Lessons learned from Project Charleston

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ARPA-E Low-Energy Nuclear Reactions Workshop

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Agenda

1. Project Charleston
2. The opportunity
3. Lessons learned
4. An example from quantum computing
5. Closing comments

Project Charleston was a multi-year, multi-institution program to re-evaluate cold fusion to a high standard of scientific rigor

- The research portfolio included **8 academic groups new to LENR**, **10 experienced LENR researchers/groups**, and **8 unsuccessful collaboration attempts***
- **12 calorimeter designs were qualified**
- Google coordinated and funded the projects; no lab work was conducted at Google

The goal was to find a "reference experiment" for cold fusion

- We have not found it yet, but we published what we learned (27 papers so far)
- *"... the search for a reference experiment for cold fusion remains a worthy pursuit..."*

More information about Project Charleston was presented at ICCF-23

* There is a limit to what can be disclosed because our collaborations were under NDA

nature
Volume 570 Issue 7759, 6 June 2019
Published online 27 May 2019
Author's link: https://rdcu.be/bEAsT

PERSPECTIVE

https://doi.org/10.1038/s41586-019-1256-6

Revisiting the cold case of cold fusion

Curtis P. Berlinguette[1,2,3,4]*, Yet-Ming Chiang[5], Jeremy N. Munday[6,7], Thomas Schenkel[8], David K. Fork[9], Ross Koningstein[9] & Matthew D. Trevithick[9]*

The 1989 claim of 'cold fusion' was publicly heralded as the future of clean energy generation. However, subsequent failures to reproduce the effect heightened scepticism of this claim in the academic community, and effectively led to the disqualification of the subject from further study. Motivated by the possibility that such judgement might have been premature, we embarked on a multi-institution programme to re-evaluate cold fusion to a high standard of scientific rigour. Here we describe our efforts, which have yet to yield any evidence of such an effect. Nonetheless, a by-product of our investigations has been to provide new insights into highly hydrided metals and low-energy nuclear reactions, and we contend that there remains much interesting science to be done in this underexplored parameter space.

https://groups.chem.ubc.ca/cberling/charleston/

The opportunity

Interest in fusion has increased remarkably this past year

April 8, 2021: TAE raises $280 million from new and existing investors (total of $880 million to date)

Aug 8, 2021: National Ignition Facility experiment puts researchers at threshold of fusion ignition

June 16, 2021: Canadian startup General Fusion says pilot plant could turn on in 2025

Sep 8, 2021: MIT-designed project achieves major advance toward fusion energy

Oct 18, 2021: Nuclear Fusion Edges Toward the Mainstream

"There aren't many fusion projects in the world, but there are many investors."

Nobody knows which technology will win

Magnetic Confinement Fusion (MCF)

- Tokamak
  - ITER (France)
  - Tokamak Energy (UK)
  - Commonwealth Fusion (USA)
- Field Reversed Configuration (FRC)
  - TAE Technologies (USA)
  - Helion (USA)
- Magnetized Target Fusion (MTF)
  - General Fusion (Canada/UK)

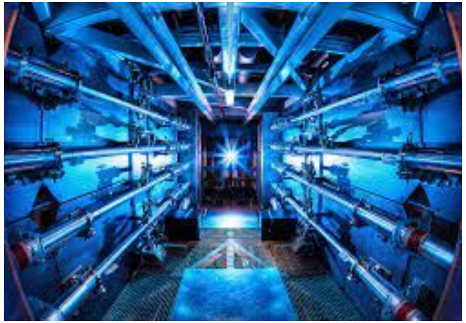
Inertial Confinement Fusion

- National Ignition Facility (LLNL)
- First Light Fusion (UK)
- Marvel Fusion (Germany)

Zeta pinch (Z-pinch)

- Zap Energy (USA)





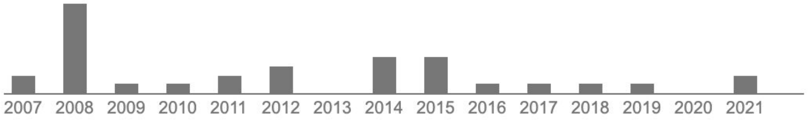
What would it take for Low-Energy Nuclear Reactions (LENR) to be included here?

Lessons learned

My backstory

The need for triggering in cold fusion reactions

Authors	M McKubre, F Tanzella, PL Hagelstein, K Mullican, M Trevithick
Publication date	2006
Book	Condensed Matter Nuclear Science
Pages	199-212
Description	Extensive experimentation with palladium wire cathodes electrolyzed in heavy water has identified loading, initiation and triggering criteria associated with the production of excess heat. In early experiments the loading and triggering were both achieved by electrochemical means and the initiation process was adventitious. This paper discusses the origins of these different effects and suggests means to optimally meet the different criteria for excess heat production as a step towards the attainment of experimental reproducibility.
Total citations	Cited by 36



Scholar articles: The need for triggering in cold fusion reactions
M McKubre, F Tanzella, PL Hagelstein, K Mullican… - Condensed Matter Nuclear Science, 2006
Cited by 36 Related articles All 10 versions

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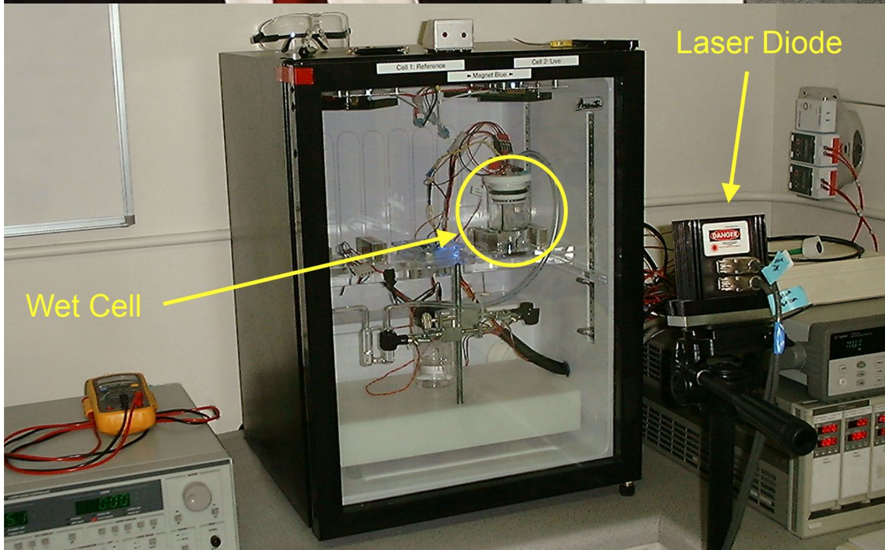


1. Don’t do this alone

Failure to effectively share the best of what is known has impeded scientific progress.

“Collectively we have the answer, individually none of us does!”

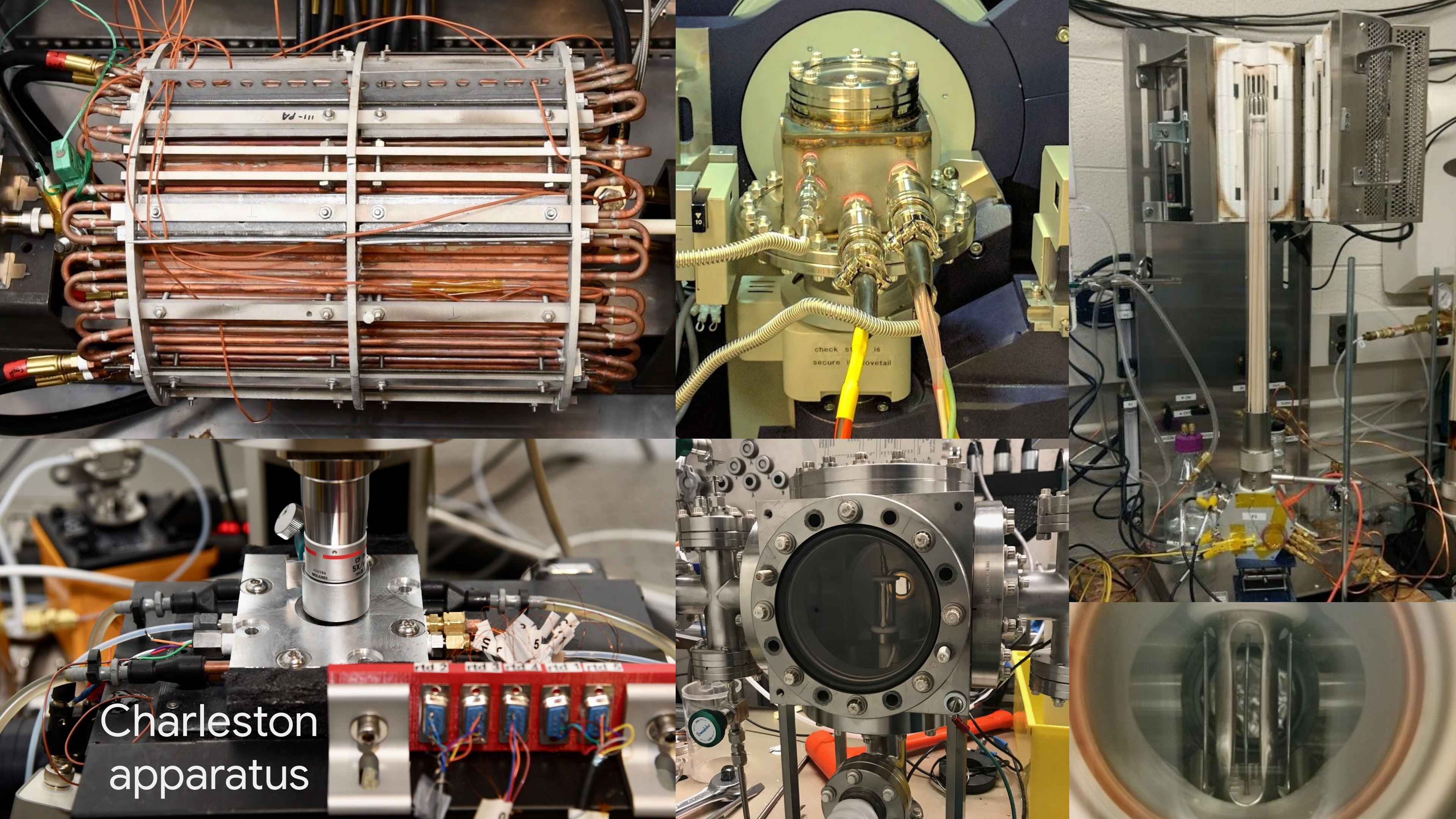
- Michael McKubre, ICCF-20, Sendai, Japan (2016)

Photo credit: Miki Chiang

2. Don’t do this undercapitalized

Stop the cycle of underfunded experiments leading to inconclusive results.

We know what these experiments really cost.



Charleston apparatus

3. Question, don't sell

Most apparently anomalous results have a more probable prosaic explanation.

Humility is conducive to credibility.

> *"When you have eliminated the impossible, whatever remains, however improbable, must be the truth."*
>
> \- Sir Arthur Conan Doyle, stated by Sherlock Holmes in The Sign of the Four (1890)

4. Align interests

Aspiring to publish in high-impact, peer-reviewed journals goes a long way towards aligning the interests of researchers, program managers and funders.

nature
SUPPLEMENTARY INFORMATION
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Co-signatories to the Nature Perspective (information as of 27 May 2019)

University of British Columbia
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Google: Dr. Craig H. Barratt, Former SVP; Mr. John Giannandrea, Former SVP; Dr. Seid Sadat, Former Contractor

5. Drop past baggage

The past is the past; the future is what we make of it.

Times are different now.

Tactical tips*

- Put the design of experiment through a peer review process prior to running the experiment
- Have calibration that exceeds the duration and operating conditions of the experiment
- Archive all models, methods, raw data, and metadata on all measurement channels
- Facilitate independent analysis of the raw data
    - Independent replication is nice to have
- Use nuclear diagnostics in addition to calorimetry

- Draft an outline of the paper you want to publish while you are designing the experiment. Formulate clear hypotheses. Sketch an “iconic plot”. Figure out what you want to communicate, then collect the data without prejudice.

* Credit: David Fork, Google Research

Our experience

1. Cold fusion was not bad for our careers
2. We are able to publish in high-impact, peer-reviewed journals
3. Excellent students and postdocs are enthusiastic about cold fusion
4. Leadership matters - a lot
5. We had fun!

“When you go on an exploration with good people, you are bound to find something interesting.”

- Curtis Berlinguette reflecting upon the publication of our Nature Perspective (2019)

An example from quantum computing

arXiv.org > quant-ph > arXiv:1203.5813

https://arxiv.org/abs/1203.5813

Quantum Physics

[Submitted on 26 Mar 2012 (v1), last revised 10 Nov 2012 (this version, v3)]

Quantum computing and the entanglement frontier

John Preskill

Quantum information science explores the frontier of highly complex quantum states, the "entanglement frontier." This study is motivated by the observation (widely believed but unproven) that classical systems cannot simulate highly entangled quantum systems efficiently, and we hope to hasten the day when well controlled quantum systems can perform tasks surpassing what can be done in the classical world. One way to achieve such "quantum supremacy" would be to run an algorithm on a quantum computer which solves a problem with a super-polynomial speedup relative to classical computers, but there may be other ways that can be achieved sooner, such as simulating exotic quantum states of strongly correlated matter. To operate a large scale quantum computer reliably we will need to overcome the debilitating effects of decoherence, which might be done using "standard" quantum hardware protected by quantum error-correcting codes, or by exploiting the nonabelian quantum statistics of anyons realized in solid state systems, or by combining both methods. Only by challenging the entanglement frontier will we learn whether Nature provides extravagant resources far beyond what the classical world would allow.

Comments:	18 pages, 8 figures. Rapporteur talk at the 25th Solvay Conference on Physics ("The Theory of the Quantum World"), 19-22 October 2011. (v2): References added. (v3): Typo corrected
Subjects:	**Quantum Physics (quant-ph)**; Strongly Correlated Electrons (cond-mat.str-el)
Report number:	CALT 68-2867
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Quantum Physics

[Submitted on 31 Jul 2016 (v1), last revised 5 Apr 2017 (this version, v3)]

Characterizing Quantum Supremacy in Near-Term Devices

Sergio Boixo, Sergei V. Isakov, Vadim N. Smelyanskiy, Ryan Babbush, Nan Ding, Zhang Jiang, Michael J. Bremner, John M. Martinis, Hartmut Neven

A critical question for the field of quantum computing in the near future is whether quantum devices without error correction can perform a well-defined computational task beyond the capabilities of state-of-the-art classical computers, achieving so-called quantum supremacy. We study the task of sampling from the output distributions of (pseudo-)random quantum circuits, a natural task for benchmarking quantum computers. Crucially, sampling this distribution classically requires a direct numerical simulation of the circuit, with computational cost exponential in the number of qubits. This requirement is typical of chaotic systems. We extend previous results in computational complexity to argue more formally that this sampling task must take exponential time in a classical computer. We study the convergence to the chaotic regime using extensive supercomputer simulations, modeling circuits with up to 42 qubits - the largest quantum circuits simulated to date for a computational task that approaches quantum supremacy. We argue that while chaotic states are extremely sensitive to errors, quantum supremacy can be achieved in the near-term with approximately fifty superconducting qubits. We introduce cross entropy as a useful benchmark of quantum circuits which approximates the circuit fidelity. We show that the cross entropy can be efficiently measured when circuit simulations are available. Beyond the classically tractable regime, the cross entropy can be extrapolated and compared with theoretical estimates of circuit fidelity to define a practical quantum supremacy test.

Comments:	Increased circuit depth, added one author, updated references. 23 pages, 15 figures
Subjects:	**Quantum Physics (quant-ph)**
Journal reference:	Nature Physics 14, 595-600 (2018)
DOI:	10.1038/s41567-018-0124-x
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This article is in the 99th percentile (ranked 3rd) of the 341,305 tracked articles of a similar age in all journals and the 99th percentile (ranked 2nd) of the 1,046 tracked articles of a similar age in *Nature*

Article | Published: 23 October 2019

Quantum supremacy using a programmable superconducting processor

Frank Arute, Kunal Arya, Ryan Babbush, Dave Bacon, Joseph C. Bardin, Rami Barends, Rupak Biswas, Sergio Boixo, Fernando G. S. L. Brandao, David A. Buell, Brian Burkett, Yu Chen, Zijun Chen, Ben Chiaro, Roberto Collins, William Courtney, Andrew Dunsworth, Edward Farhi, Brooks Foxen, Austin Fowler, Craig Gidney, Marissa Giustina, Rob Graff, Keith Guerin, Steve Habegger, Matthew P. Harrigan, Michael J. Hartmann, Alan Ho, Markus Hoffmann, Trent Huang, Travis S. Humble, Sergei V. Isakov, Evan Jeffrey, Zhang Jiang, Dvir Kafri, Kostyantyn Kechedzhi, Julian Kelly, Paul V. Klimov, Sergey Knysh, Alexander Korotkov, Fedor Kostritsa, David Landhuis, Mike Lindmark, Erik Lucero, Dmitry Lyakh, Salvatore Mandrà, Jarrod R. McClean, Matthew McEwen, Anthony Megrant, Xiao Mi, Kristel Michielsen, Masoud Mohseni, Josh Mutus, Ofer Naaman, Matthew Neeley, Charles Neill, Murphy Yuezhen Niu, Eric Ostby, Andre Petukhov, John C. Platt, Chris Quintana, Eleanor G. Rieffel, Pedram Roushan, Nicholas C. Rubin, Daniel Sank, Kevin J. Satzinger, Vadim Smelyanskiy, Kevin J. Sung, Matthew D. Trevithick, Amit Vainsencher, Benjamin Villalonga, Theodore White, Z. Jamie Yao, Ping Yeh, Adam Zalcman, Hartmut Neven & John M. Martinis -Show fewer authors

Nature **574**, 505–510 (2019) | Cite this article

861k Accesses | **1102** Citations | **6088** Altmetric | Metrics

Abstract

The promise of quantum computers is that certain computational tasks might be executed exponentially faster on a quantum processor than on a classical processor[1]. A fundamental challenge is to build a high-fidelity processor capable of running quantum algorithms in an exponentially large computational space. Here we report the use of a processor with programmable superconducting qubits[2,3,4,5,6,7] to create quantum states on 53 qubits, corresponding to a computational state-space of dimension 2^{53} (about 10^{16}). Measurements from repeated experiments sample the resulting probability distribution, which we verify using classical simulations. Our Sycamore processor takes about 200 seconds to sample one instance of a quantum circuit a million times—our benchmarks currently indicate that the equivalent task for a state-of-the-art classical supercomputer would take approximately 10,000 years. This dramatic increase in speed compared to all known classical algorithms is an experimental realization of quantum supremacy[8,9,10,11,12,13,14] for this specific computational task, heralding a much-anticipated computing paradigm.

"All the News That's Fit to Print"

The New York Times

Late Edition

Today, plenty of sunshine, rather mild, high 67. **Tonight,** clear, seasonable, low 51. **Tomorrow,** sunshine and patchy clouds, light wind, high 64. Weather map is on Page B11.

VOL. CLXIX . . . No. … NEW YORK, THURSDAY, OCTOBER 24, 2019 $3.00

Google Claims Computing Feat Akin to 1st Flight

By CADE METZ

SANTA BARBARA, Calif. — Google said on Wednesday that it had achieved a long-sought breakthrough called "quantum supremacy," which could allow new kinds of computers to do calculations at speeds that are inconceivable with today's technology.

The Silicon Valley giant's research lab in Santa Barbara, Calif., reached a milestone that scientists had been working toward since the 1980s: Its quantum computer performed a task that isn't possible with traditional computers, according to a paper published in the science journal Nature.

A quantum machine could one day drive big advances in areas like artificial intelligence and make even the most powerful supercomputers look like toys. The Google device did in 3 minutes 20 seconds a mathematical calculation that supercomputers could not complete in under 10,000 years, the company said in its paper.

Scientists likened Google's announcement to the Wright brothers' first plane flight in 1903 — proof that something is really possible even though it may be years before it can fulfill its potential.

GOOGLE

Google said its computer could process in 3 minutes 20 seconds what would take a supercomputer more than 10,000 years to do.

"The original Wright flyer was not a useful airplane," said Scott Aaronson, a computer scientist at the University of Texas at Austin who reviewed Google's paper before publication. "But it was designed to prove a point. And it proved the point."

Still, some researchers cautioned against getting too excited about Google's achievement since so much more work needs to be done before quantum computers can migrate out of the research lab. Right now, a single quantum

Continued on Page A13

Lesson learned

Build consensus around a definition of success well in advance of expected results. This also helps define a credible experiment.

Proposed action item

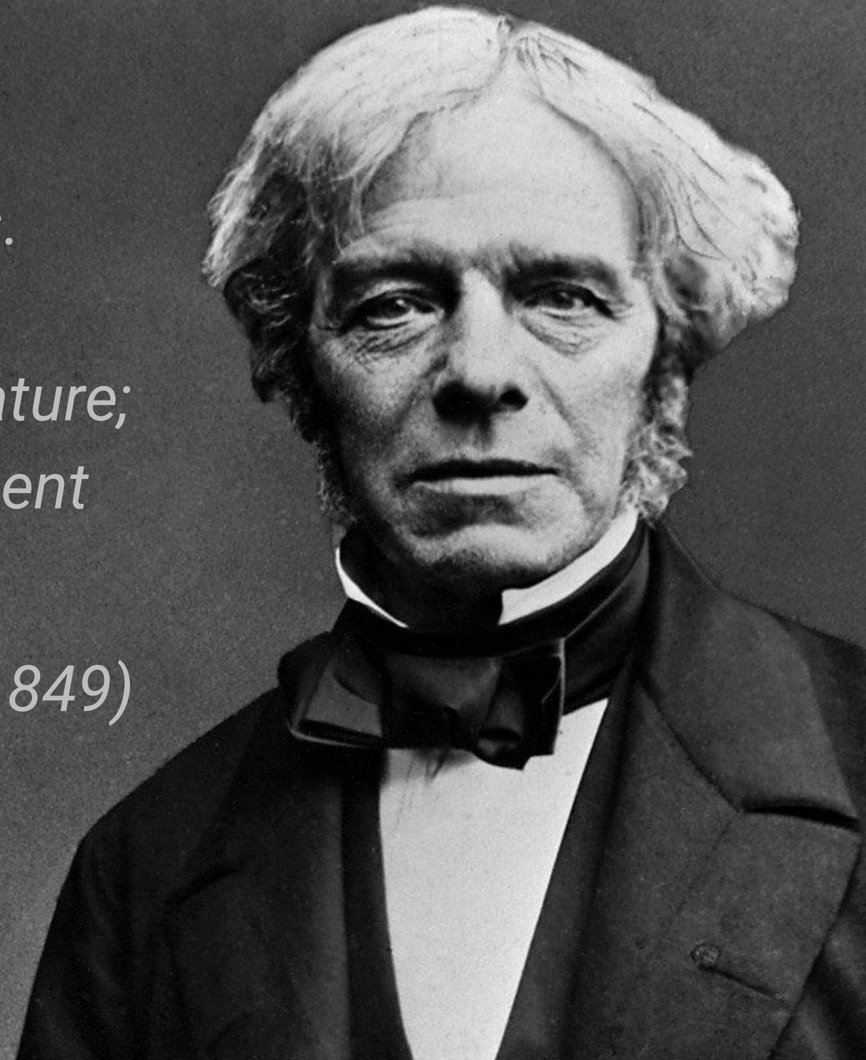
Define, publish, and invite feedback on a definition of a successful LENR experiment. This could be a tangible result from this workshop.

Closing comments

1. We have an opportunity to come together under ARPA-E's leadership for the good of the country and the good of the planet.
2. Will we take collective action to find, validate, and publish a "reference experiment" to teach the best of what we know?
3. The entrepreneurial bonanza that a generally accepted proof of concept could unleash would be an unfakable sign of our success.

ALL THIS IS A DREAM.
Still examine it by a few experiments.
Nothing is too wonderful to be true,
if it be consistent with the laws of nature;
and in such things as these, experiment
is the best test of such consistency.

- Michael Faraday (1849)



Work. Finish. Publish.

Acknowledgements

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Physics

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Physics

Google

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Scientific Lead

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Lessons learned from Project Charleston

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